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**Effect of Rowing Distance on Lumbar Flexion and
Erector Spinae Electromyography on a Slide versus
Fixed Base Rowing Ergometer**

By

Nicole Yvette Kelp

In Partial Completion
Of the Requirements of the Degree
Masters of Science

Kathleen Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

Chair, Dr. Dave Suprak

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Dr. Harsh Buddhadev

MASTER'S THESIS

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Nicole Yvette Kelp

July 21, 2017

**Effect of Rowing Distance on Lumbar Flexion and
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Fixed Base Rowing Ergometer**

A Thesis

Presented to

The Faculty of

Western Washington University

In Partial Fulfillment

Of the Requirements for the Degree

Masters of Science

By

Nicole Yvette Kelp

July 2017

Abstract

The purpose of this study was to determine if there was a significant effect of distance on lumbar flexion and erector spinae (ES) muscle activity while rowing on a slide-based Row Perfect 3 (RP3) versus a fixed-based Concept 2 (C2) ergometer during a 1000-m time trial in competitive female rowers. Low back pain is a common complaint among rowers and certain variables such as increased lumbar flexion, timing of peak flexion and ES muscle activity have been associated with risk for low back injury. A better understanding of the effects of fatigue on the trunk and hip extensors may provide coaches and rowers knowledge on how to prevent low back pain and injury.

Subjects performed one 1000-m time trial on each rowing ergometer, separated by approximately 48 hours. During each time trial, lumbar flexion and electromyography (EMG) of the ES were collected at four different distances: 250-m, 500-m, 750-m and 950-m. Capture time for each distance was approximately 10 seconds.

Statistical analysis was performed using 3-way repeated measures analyses of variance (ANOVA) for ergometer style, distance, and percent drive phase on lumbar flexion and ES activity. Two-way repeated measures ANOVA was used for ergometer style and distance on peak lumbar flexion and timing of peak. There was no significant effect of distance or ergometer style on time to peak, peak and mean lumbar flexion, and right ES activity. Significantly greater ES activation was accompanied by significantly less mean lumbar flexion at 60% of the drive phase compared to 10 and 20%. Although there was no significant effect of ergometer style on right lumbar ES, there was a significantly higher left ES activation on the RP3 versus the C2.

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Chapter 1

The Problem and Its Scope

Introduction

Rowing is primarily an aerobic sport and one of the most physically demanding (Hagerman, Hagerman & Mickelson, 1979). Rowing at a collegiate level includes year round training that involves the use of ergometers as an indoor training tool. This equipment is necessary for improving technique and fitness during the winter months or poor weather and is an effective standardized tool for assessing a rower's ability (Halladay, 1990). Ergometer training can consist of anything from a long steady-state row, interval row with rest between shorter higher intensity sections, or race time trials. Race time trials are usually 2000 meters and require an all-out effort (USRowing, 2016). With increased duration on the rowing ergometer, an associated increased risk of injury was found in a review of injury prevalence among rowers (Teitz, O'Kane, Lind, & Hannafin, 2002). One of the most common rowing injuries includes injury to the spine or ribs, both skeletal and muscular (Dragoni, Giombini, Di Cesare, Ripani, & Magliani, 2007; Maurer, Soder, & Baldisserotto, 2011).

Low back pain (LBP) is prevalent among rowers with one study finding approximately 32% of a large group of rowers experiencing LBP (Teitz et al., 2002). Low back pain is defined as the sensation of pain, ache or discomfort in the region between T12 and the inferior gluteal folds, strong enough to limit usual activity (Dionne, Dunn, Croft, Nachemson, Buchinder, Walker et al., 2008). The specific biomechanics of the rowing stroke may be the cause of low back pain. Rowers experience high magnitudes of shear and compressive forces at the spine during the "drive" phase of the stroke, during repeated flexion and extension, and in the presence

of significant fatigue (Hannafin and Hosea, 2001; Hosea, Boland, McCarthy, & Kennedy, 1984; Morris, Smith, Payne, Galloway, & Wark, 2000). As a rower becomes fatigued, increased flexion in the trunk has been observed (Bull and McGregor, 2000; Caldwell, McNair, & Williams, 2003; Pollock, Jones, Jenkyn, Ivanova, & Garland et al, 2009; 2012). Muscle activity of the trunk extensors and flexors has been closely examined to determine if there is a correlation between fatigue and spinal flexion. Inconclusive results have been found regarding the relationship between fatigue of the erector spinae group and increased spinal flexion during rowing and lifting tasks (Caldwell et al., 2003; Dolan and Adams, 1998; Holt, Bull, & Cashman, 2003; Pollock et al., 2009; 2012). These factors increase the risk for overuse injuries, such as disc degeneration and laxity in the viscoelastic structures of the lumbar spine (Maurer, Sider, & Baldisserotto, 2011; Olson, Li, & Solomonow, 2004).

Over the years, various styles of rowing ergometers have been designed to better simulate on-water rowing (Steer, McGregor, & Bull, 2006). The two main styles of ergometers include a fixed-base and a slide-base. Several groups have found that fixed-base ergometers, such as the Concept2, require more mechanical work, increase lumbar flexion at the “catch”, and do not simulate on-water rowing accurately (Bernstein, Webber, & Woledge, 2002; Caldwell et al., 2003; Elliot, Lyttle, & Birkett, 2002; Greene, Sinclair, Dickson, Colloud, & Smith, 2013; Wilson, Gissane, & McGregor, 2014). Authors also found that while slide-based ergometers may have a higher energy demand, they induce less spinal flexion, and better simulate on-water rowing (Benson, Abendroth, King, & Swensen, 2011; Elliot et al., 2002; Fleming, Donne, & Mahony, 2014; Holsgarrd-Larsen and Jensen, 2010). These differences may possibly be due to the increased weight of the fixed ergometer in comparison to that of the slide-based ergometer and the stationary fly wheel that requires the rower to increase their center of mass displacement,

compared to the slide, where the rower and flywheel meet half way up the rail. The increased weight and displacement of the fixed-base ergometer may increase muscle fatigue since it requires more mechanical work, for each drive. The slide-based ergometer, although it has a higher energy demand, requires less mechanical work as the weight the rower is pressing away is much lower. The differences in how the rower is fatigued, physiological or mechanical, may play a role on the muscle activity of the erector spinae and lumbar flexion (de Campos Mello, Bertuzzi, Franchini, & Candau, 2014; Greene et al., 2013). No study has compared the slide-based ergometer, Row Perfect 3, to the fixed ergometer, Concept2, in regards to how distance affects the relationship between muscle activity of the erector spinae and lumbar flexion.

Purpose of the Study

The purpose of this study was to determine if there was a significant effect of distance on lumbar flexion and lumbar erector spinae muscle activity while rowing on a slide-based Row Perfect 3 (RP3) rowing ergometer versus a fixed-based Concept 2 (C2) during a 1000 m time trial in competitive female rowers.

Statement of the Null Hypothesis

There is no significant effect of distance on mean and peak lumbar flexion and lumbar erector spinae muscle activity between rowing ergometer styles during a 1000 m rowing ergometer time trial.

Significance of the Study

Continuous land-based training on a rowing ergometer increases a rower's risk for low back pain and injury (Bernstein, 1994). This may cause a rower to lose 2-5 training days and worsen their performance. It is understood that, during rowing, the spine undergoes degrees of spinal flexion repetitively and that decreased muscle activity has been reported in the concentric

muscle action of the trunk extensors. The relationship between muscle activity of the lumbar erector spinae muscles and lumbar flexion has not yet been determined (Caldwell et al., 2003). A better understanding of the effects of fatigue on the trunk and hip extensors may provide coaches and rowers knowledge on how to prevent low back pain and spinal injury.

Limitations of the Study

1. Subjects in this study were all competitive female rowers and results are not generalized to other subject populations or male populations.
2. It was encouraged that all subjects included in the study perform the 1000 m rowing trial to the best of their ability in an all-out effort, making it difficult to control for wattage and individual motivation of the rower.
3. Spinal flexion was measured using inertial measurement units on the skin and may not fully reflect the movement of the spine under the skin, due to skin motion artifact.
4. Muscle activity of the lumbar erector spinae was measured using surface EMG and may have crosstalk with the electrical activity of the surrounding muscles.

Definition of Terms

Bow: Front of boat (USRowing, 2016)

Catch: The beginning of the stroke when the rower is fully compressed, knees bent, arms straight and oar is in the water (US Rowing, 2016)

Drive: The portion of the stroke where the rower is exerting force against the foot stretchers and pulling the oar into the body to move the boat forward (US Rowing, 2016)

Finish: The end of the drive phase when the rower is extended at the knees, and hips with the oar pulled into the body (US Rowing, 2016)

IMU: Inertial Measurement Unit, comprised of accelerometers, gyroscopes and magnetometer. A sensor based solution for calculating human kinematics (Noraxon USA, 2017)

Kinematics: Describing and measuring the motion of the body with references to joints and segments, not the forces that caused the motion (Whiting and Zernicke, 2008)

Lay Back: The part of the rowing cycle when the knees and hips extend together while the elbows flex and pull the oar into the chest.

Lumbar flexion: A forward bend that decreases the angle of the lumbar spine between the spinous processes of L1 and L5 (Adam and Dolan, 1991; Whiting & Zernicke, 2008)

Muscle fatigue: A decrease in a muscle's ability to perform physical actions, often measured by a decrease in force or a change in electromyography activity (Enoka & Duchateau, 2008)

MVC: Maximum voluntary contraction of a specific muscle or group of muscles, used to normalize data obtained from an electromyography (Caldwell et al., 2003)

Port: Left side of the boat when facing the direction the boat is heading/ front of the boat (see Bow) (USRowing, 2016)

Recovery: A relaxed movement back up to the slide and into the catch (US Rowing, 2016)

Rowing ergometer: A land-based training tool that attempts to mimic on water rowing (Concept2 Inc., 2016)

Slide: The tracks on the rowing ergometer or boat that the seat slides on (Concept2 Inc., 2016)

Starboard: Right side of the boat when facing the direction the boat is heading/front of boat (USRowing, 2016)

Stroke: The sequence of the drive and recovery phases (USRowing, 2016)

Stern: Back of boat (USRowing, 2016)

Chapter II

Review of Literature

Rowing is becoming increasingly popular in college athletics, with the NCAA reporting 142 member schools sponsoring women's rowing. This is a substantial increase from the 43 schools which offered women's rowing in 1982 (National Collegiate Athletic Association, 2012). With the increase of athletes to the sport, an increase in complaint of low back pain has also been reported (Smolijanovic, Bojanic, Hannafin, Hren, Delimar, & Pecina, 2009; Teitz, O'Kane, Lind & Hannafin, 2002; Verrall and Darcey, 2014).

Low back pain is one of the most common overuse injuries to occur in rowing as the athletes experience repetitive high levels of flexion and force on the spine during a race and practice (Holt, Bull, Cashman, & McGregor, 2003). In the off -season, rowing ergometers are used on a daily basis with longer durations spent rowing as the training is focused on endurance (Holt et al., 2003; USRowing, 2016). With so much time spent on the ergometer, it is important to determine the variables that may be causing the low back pain experienced. Studies on rowing and spinal kinematics have revealed that low back pain is a consequence of high degrees of flexion in the spine, repetitive spinal flexion, high compressive and shear loads, and muscle tightness and fatigue (Adams, McMillan, Green, Dolan, 2000; Caldwell, McNair & Williams, 2003; Hannafin & Hosea, 2001; Hosea, Boland, McCarthy & Kennedy, 1984; Morris, Smith, Payne, Galloway, & Wark, 2000; Wilson, Gissane, & McGregor, 2013). Just as these variables affect the rower, the style of ergometer can also affect the kinematics and biomechanics of the spine during the rowing stroke. The research synthesized in this literature review will focus on low back pain in rowers, the known causes, and how ergometer style, fixed base versus slide based, may affect the biomechanics and kinematics of the rowing stroke. With this knowledge, the aim of this study is to provide a direct comparison of a slide-based ergometer to a fixed-base

ergometer, specifically observing lumbar flexion at the catch and muscle activity of the lumbar erector spinae muscles.

The Rowing Stroke

The rowing stroke consists of two phases; the drive phase and recovery phase. In the drive phase, force is applied to the oar in order to move the boat. In the recovery phase, the rower is coming up the slide, letting the boat glide as they set up to take the next stroke. The transition between the recovery and the drive is called the “catch.” When the rower is fully compressed up the slide. In this position, the arms are extended, knees are flexed and there is flexion at the hips. The lumbar and thoracic spine should remain in a neutral posture rather than curved during this phase. This position helps the rower transfer the energy from the hips into the legs and through the feet to produce enough force to extend the legs and hip at the same time, while maintaining straight spine and arms. This propulsive action off of the foot stretcher is called the “drive” phase. This is when the rower applies as much force as he or she can into the foot stretchers to extend at the knee and hip and push the seat back. The arms and spine at this first “push” are all fixed and providing the rigid body that transfers the force of the knee and hip extension into the oar. The next stage of the drive is the “lay back,” this is where the knees and hips are moving into full extension, the arms remain straight and the spine is in neutral with the scapula retracted and depressed. When the legs and hips are almost fully extended, the arms start the “row.” The arms flex at the elbow, pulling the oar into the body just below the sternum. This fully extended shoulder position with the elbows in flexion represents another transition stage called the “release.” The release is the end of the drive phase and the transition into the recovery phase. The recovery begins the instant the rower has gotten to the release and starts with the elbows extending and shoulders flexing, followed by the hips which go into approximately 90 degrees of flexion. Once the shoulders are directly stacked over the hips, flexion starts to occur at the knee

and the hip flexes into an approximate 45degree angle. The rower slides back up to the catch through the knee flexion and the stroke is repeated. (USRowing, 2016; Concept2 Inc., 2016)

Low Back Pain and Rowers

Lower back pain is a common complaint among rowers of all levels (Maurer et al., 2011; Smolijanovic et al., 2009; Teitz et al., 2002; Verrall and Darcey, 2014). Teitz et al. (2002) conducted a widespread survey of former intercollegiate rowers and found that out of 1632 athletes, 526 reported low back pain, a 32% prevalence. An older study reported 82.2% of 17 elite lightweight female rowers experience back pain (Howell, 1984). In summary, there are many possible causes of low back pain in rowers, including: high degrees of flexion in the spine, repetitive spinal flexion, high compressive and shear loads and muscle tightness and fatigue, specifically at the catch and beginning of the drive phase (Hannafin and Hosea, 2001; Hosea et al., 1984; Morris et al., 2000; Maurer et al., 2011; Sekine et al., 2014).

During a rowing stroke the spine acts as a cantilever and transfers the force exerted from the legs to the upper extremity, and into the oar (Pollock et al., 2009). Following the catch, there is a rapid increase in the anterior shear load of the L3 and L4 motion segments as the rower begins the drive, peaking at mid-drive, just before lay back. (Hannafin and Hosea, 2001; Hosea et al., 1984). Morris et al. (2000) estimated the compressive and shear forces at the lumbar spine (L4/L5) in fourteen female rowers with an average age of 19.7 years. Peak compressive and shear forces were 2694 ± 609 N and 660 ± 117 N, respectively. Similarly, Hosea et al. (1984) reported an average compressive load of 3330 N and anterior shear forces of 717 N in female rowers. The shear forces experienced by rowers makes them susceptible to disc degeneration over time (Maurer et al., 2011; Sekine et al., 2014).

It has been approximated that 70% of the rowing cycle is spent in trunk flexion (Hosea, et al., 1984). A rowing race is usually 2000 meters, lasting anywhere from 6 minutes 30 seconds to

9 minutes in competitive female rowers (USRowing, 2016; Concept2 Inc., 2016). If a rower is set to a pace of 28-30 strokes per minute (spm), this averages approximately 226 total strokes. For every stroke, the rower must come up to the catch, in the flexed trunk position, before starting the drive phase. This flexed trunk position coupled with compressive loading has been suggested as a major risk factor for low back pain (Reid and McNair, 2000). Flexion of the trunk and spine and the effect on low back pain can be separated into two categories: repetitive or cyclic flexion and end of range flexion loading. Both play a key role in the development of low back pain and take place in rowing.

Cyclic lumbar flexion. As calculated earlier, a female rower may row an average of 226 strokes in a 2000-meter race. During practice, rowers may perform approximately 1800 rowing strokes in a 90-minute training session (Caldwell et al., 2003). The repetitive nature of rowing increases the risk for injury due to the many cycles of flexion and extension. Vulnerability to the intervertebral disc injuries may increase with cyclic loading and small compressive forces. A study by Solomonow et al. (1999) found that during a 50-minute cyclic loading of the spine, laxity in the viscoelastic tissues of the spine desensitized the mechanoreceptors and dramatically reduced muscular activity that stabilized the spine. The flexion relaxation response has been the suggested mechanism for the reduction in trunk extensor muscle activation during cyclic flexion (Olson, Li, & Solomonow, 2004). It has been observed that with increasing flexion angles of the trunk, the muscle activity of the trunk muscles diminished to almost complete silence, and laxity developed in the lumbar viscoelastic structures (Olson et al., 2004). Another response of cyclic flexion and extension was an increased frequency of spasms towards the end of the exercise, indicating possible micro damage (Claude et al., 2003, Olson et al., 2004).

Trunk range of motion has been shown to increase due to the viscoelastic creep and reduction in intervertebral disc height after cyclic flexion (Dolan and Adams, 1998; Olson et al., 2004). This increase in trunk range of motion places a greater moment on the lumbar spine and may increase the risk for low back pain. The risk associated with cyclic loading of the spine is further supported by the higher incidence of disc herniation and spondylolytic changes in the lumbar spine in rowers (Soler and Calderon, 2000; Maurer et al., 2011). In a more recent study, Sekine et al. (2014) found a 45.6 % prevalence of disc degeneration in 68 collegiate rowers, especially in the lumbar spine. These responses to cyclic flexion may cause instability in the lumbar spine and compromise the integrity of the lumbar soft tissues and bony structures.

End of range flexion loading End of range flexion loading occurs when the lumbar spine is in a position where the passive structures of the spine are close to being stretched or maximally loaded, increasing the risk for pain and injury (Adams, McMillan, Green, Dolan, 2000; Adams, Hutton, Stott, 1980). Some rowers may go into a position while rowing on an ergometer that exceeds their end of flexion range (Caldwell et al., 2003; Wilson et al., 2013). Caldwell et al. (2003) studied changes in lumbar flexion across the drive phase during a 2000m-ergometer race in 16 young adult male and female rowers.

Peak flexion was found to be 74-89% of the full range of flexion in the first 50-60% of the drive phase, with the amount of flexion increasing as the time trial progressed. Wilson et al (2013) had rowers perform a standing flexion angle test to determine peak end of range flexion, then measured the amount of lumbar flexion during a rowing ergometer step test. The step test started with a power output of 160 Watts for 3 minutes at a fixed stroke rate of 18 spm, then increased in 40 Watt increments every 3 minutes with increases in stroke rate of 2 spm per step taken in the test, until exhaustion. In the final stage, they found an 11.3% increase in mid-lumbar

(L2-L4) flexion from the peak standing angle test. Although these studies indicate that rowers may exceed their end of range flexion during a rowing piece on an ergometer, little research has been done to investigate and link low back pain incidence with the end of flexion range.

Muscular fatigue and spinal flexion. Muscular fatigue of the trunk flexors and extensors has been suggested as a main cause of increased trunk flexion at the catch of a rowing stroke (Pollock et al., 2012). Some studies have noted an increase in spinal flexion and pelvic posterior tilt at the catch with increasing time on the rowing ergometer (Caldwell et al., 2003; Holt et al., 2003; Pollock et al., 2012; Wilson et al., 2013). It is proposed that, as a rower starts to fatigue, there is an increase in spinal flexion, with muscular fatigue of the trunk and pelvic muscles being one of multiple possible factors that may be causing the increased flexion observed over time.

A study by Roy et al. (1990) studied twenty- three members of a men's collegiate varsity crew team. The purpose of this study was to determine if EMG of the erector spinae muscles could identify rowers with low back pain. They measured the median frequency of the EMG power density spectrum and performed a fatigue-inducing 30-second isometric contraction at 80% MVC, then after 1 min of rest, another 5 second contraction at 80% MVC to monitor recovery from fatigue. This test was able to identify rowers with low back pain 100% of the time and identified non-low back pain rowers 93% of the time, with the median frequency parameters related to recovery as the best discriminator of low back pain. Asymmetry based on being a port or starboard rower was also found based on the median frequency parameters related to fatigability and recovery. The authors concluded that EMG spectral analysis of the erector spinae can be used to accurately assess low back pain in rowers (Roy et al., 1990).

Wilson et al. (2013) conducted an investigation with 19 male elite rowers on lumbar flexion (L2-L4) difference between fixed base ergometer rowing and on water rowing. In both the ergometer and on water conditions, maximal lumbar flexion significantly increased from the first step to the last step of the step test previously described, by $4.4^{\circ} \pm 0.9^{\circ}$ and $1.3^{\circ} \pm 1.1^{\circ}$, respectively. In comparison to the standing voluntary range of motion, peak flexion on the ergometer was 11.3% higher and peak flexion in the boat was 4.1% higher. In the ergometer testing, significant changes occurred in the sagittal kinematics of the spine over the time course of the 2000- meter trial, increasing lumbar flexion over time (Wilson et al., 2013). Previous studies have found similar results in the lumbar spine during a rowing protocol with increased amounts of flexion occurring at the lumbar spine as the rower fatigues (Caldwell et al., 2003; Bull and McGregor, 2000; Holt et al., 2000; Pollock et al., 2002).

Caldwell et al. (2003) observed 16 young adult male and female rowers and found an increase in lumbar flexion at the L1 and S1 from 75% to 90% maximum range of motion, over the course of the 2000 m rowing simulation. Amplitude of muscle activity significantly increased from approximately 50% MVC to 80% MVC during the three stages of the rowing trial, while median frequency of the erector spinae significantly decreased following the trial, indicating muscle fatigue (Caldwell et al., 2003).

Pollock et al. (2012) studied nine elite female rowers who performed a 2000-meter race on a fixed base, Concept 2 rowing ergometer. At the 1500 m mark, the spine and pelvis had increased flexion angles when compared to the 250 m mark. Specifically, at the catch, pelvic posterior tilt increased $1.9^{\circ} \pm 2.4^{\circ}$, while the spine (L3-S1, T7-T10 and T4-T7) increased flexion by $3.0^{\circ} \pm 1.9^{\circ}$. It is important to note that muscle fatigue in the spinal extensors (thoracic and

lumbar erector spinae and latissimus dorsi), gluteus maximus, and biceps femoris was not significantly correlated with increased spinal flexion in this study.

Studies on lifting tasks, rather than rowing, have also demonstrated significant increases in lumbar flexion over the duration of the task. Dolan and Adams (1998) found that with repetitive forward bending and lifting, there were significant increases in lumbar flexion from 83% to 90% and increased fatigue in the erector spinae muscles measured by EMG median frequency. However, there was a poor correlation between the muscle fatigue and increased lumbar flexion, possibly due to the EMG calculations of fatigue used for the dynamic task (Dolan and Adams, 1998).

Ergometer Style Differences

Rowing ergometers, or “ergs,” are an on-land practice tool that attempts to mimic on-water rowing (Steer, McGregor, & Bull, 2006). There are different types of ergometers, but the most widely used is an air-braked stationary ergometer like the Concept II (C2). On this ergometer, the seat slides on the rail while the flywheel and foot stretchers remain fixed (Fleming, Donne, & Mahony, 2014). During the drive phase of the rowing stroke, the rower pushes off against the foot stretcher and propels the seat and their body backward away from the stationary base, ultimately pressing their full body weight and increasing the displacement of the center of mass (COM), unlike on water rowing. On water, the boat continues to run beneath the sliding seat the rower is on, bringing their feet closer to them rather than having to pull themselves all the way up from where they ended the stroke (Elliot et al., 2002; de Campos Mello et al., 2014).

Another rowing ergometer, the Row Perfect 3 (RP3), was designed to simulate on-water rowing as it is a dynamic, or slide based, air-braked ergometer. On this ergometer, both the

flywheel and foot stretcher are able to move along the rail just as the seat does, mimicking the open chain kinetics of rowing in a boat (Elliot et al., 2002; Fleming et al., 2014). Another feature of the RP3 is a narrower rail, increasing the instability of the seat, forcing rowers to balance themselves as they would in a rowing shell. As the rower pushes off the foot stretchers, the seat and the flywheel both slide away from each other, decreasing the horizontal displacement of the COM of the rower on the rail and decreasing the amount of weight that is being pushed away as the flywheel has an approximate mass of 17.5 kg comparable to the boat and oars carried by one rower versus a rower's body weight being anywhere from 55kg to 85kg (Bernstein et al., 2002; Elliot et al., 2002; Fleming et al., 2014). Concept II has also tried to make their stationary ergometer mimic on-water rowing by placing it atop slides. The approximate weight of this dynamic ergometer style would then be 26 kg (de Campos Mello et al., 2014).

Many authors have investigated the differences between a fixed ergometer and a slide-based ergometer, most observing the Concept II with and without slides (Benson et al., 2011; Greene et al., 2013; de Campos Mello et al., 2014; Hoisgaard-Larsen and Jensen, 2010), some comparing on-water rowing to a fixed Concept II ergometer (Fleming et al., 2014; de Campos Mello et al., 2014; Wilson et al., 2013), and others comparing the RP3 to on-water and stationary Concept II ergometers (Bernstein et al., 2002; Elliot et al., 2002; Fleming et al., 2014; Greene et al., 2010, Wilson et al., 2013). These three ergometer styles, the RP3, Concept II stationary (C2s) and Concept II dynamic (C2d), have all been compared to evaluate the rowers' mechanics and physiological responses. Only recently, studies have been able to compare these ergometer styles to on-water rowing, as it is difficult to control the weather, water current, and use certain equipment wirelessly and open to the elements. This section will discuss the various

physiological differences and similarities of the ergometer styles, focusing primarily on the biomechanical differences and how this may relate to injury of the low back.

Physiological and biomechanical differences in ergometer styles. Variances have been observed between the dynamic and stationary ergometer. De Campos Mello et al. (2014) studied eight male rowers with an average age of 23.8 ± 5.5 years. This study compared the physiological ($\text{VO}_{2\text{peak}}$) and power differences between the C2 slide and C2 fixed to on-water rowing during incremental exhaustion tests and a 2000-meter race simulation. Peak oxygen uptake ($\text{VO}_{2\text{peak}}$) was significantly higher on the dynamic ergometer compared to the slide-based ergometer. The $\text{VO}_{2\text{peak}}$ also correlated to the mean VO_2 during the on-water race simulation. They concluded that the slide-based ergometer was more beneficial for evaluating a rower's ability and was more closely related to on-water rowing in terms of physiological cost (de Campos Mello et al., 2014).

Alternatively, Holsgaard-Larsen and Jensen (2010) reported that slide-based ergometers are similar to fixed-base in terms of aerobic demands. Seven elite female rowers from the Danish National Team were recruited to perform three submaximal 6-minute tests at 40%, 55% and 70% of their all-out mean power output. Subjects were tested on a C2d and a C2s. Maximum and mean forces were lower on the C2d during the two highest intensities at 4.7- 9% and 3.2-10.6 % difference between the conditions, respectively. A higher stroke rate was also observed on the C2d, representing a 1-11.4% difference. Unlike the previous test, the VO_2 , power output, heart rate and R-value (expired CO_2 / inspired O_2) were all comparable between the ergometer styles, indicating that they had similar economy, which is contradictory to the previous study mentioned (Holsgaard-Larsen and Jensen, 2010; de Campos Mello et al., 2014).

In the two previous studies, a higher economy was hypothesized for the slide-based ergometer due to the decreased amount of weight the rower had to push away. The rower moves the device itself, rather than their body weight on a slide-based ergometer and, as the C2d has an approximate weight of 26 kg compared to the average body weight of 70-80 kg for males and 60-70 kg for females, the biomechanical load is lower (Elliot et al., 2002; Holsgaard-Larsen and Jensen, 2010; de Campos Mello et al., 2014).

Another study comparing the differences in the C2d and C2s found that collegiate rowers had a higher stroke rate and lower stroke force to maintain the same power output on the C2d (Benson et al., 2011). Thirty-four collegiate rowers, 17 men and 17 women, performed a 1000 m ergometer trial on each ergometer with power outputs calculated from the average 500 m split during a 2000 m ergometer all out trial. Due to the higher stroke rates, an increase in cardiopulmonary demand was found on the C2d. A greater pulmonary demand was also found on the C2d, due to rowers' need to increase the strokes per minute in order to maintain power output done by shortening recovery time and having a longer drive (Benson et al., 2011).

Trunk motion and EMG on slide- and fixed-based ergometers and on-water rowing.

A study by Wilson et al. (2013) gives good insight into how lumbar flexion increases with time spent on an ergometer. Lumbar motion in the sagittal plane was assessed in 19 elite male rowers. Although there was no direct measurement of fatigue, rowers were asked to row at a certain wattage and stroke rate during the step test and, if they were unable to maintain that power output or stroke rate, the test was over and the rower was considered "fatigued to exhaustion." Increased lumbar flexion was seen in both the boat and ergometer from first stage to last stage, $4.4^{\circ} \pm 3.7^{\circ}$ and $1.3^{\circ} \pm 4.5^{\circ}$, respectively. The difference in maximum voluntary flexion angle and lumbar angle at the last step of the test was $5.3^{\circ} \pm 7.1^{\circ}$ for the erg and $2.0^{\circ} \pm 4.8^{\circ}$ for boat.

Statistically significant increases in lumbar flexion were only found on the fixed ergometer (Wilson et al., 2013). This finding may be due to a higher energy requirement needed on the fixed-based rowing ergometer, as seen previously (Greene et al., 2013).

Greene et al. (2013) compared the joint mechanical energy, power production, and segment coordination throughout the drive and recovery phases on a C2d, C2s and a Row Perfect (RP) in 14 elite male rowers (age 25.1 ± 4.5 years). Results of this study found a delay in the delivery of power at the handle of the C2s ergometer, compared to the RP and C2d. Peak power was found between 10-15% of the stroke on the RP and C2d, whereas on the C2s peak power occurred around 25-40% of the stroke. Total joint mechanical energy production was greater in the C2s, however the mechanical energy delivery to the handle of the ergometer was similar to that on the other ergometers, indicating that the extra mechanical energy produced at the lower limbs is not actually used to produce force, resulting in an increased energy demand. This result was also observed in a study by Bernstein et al. (2002). The delay in power at the handle was attributed to the fixed foot stretcher and the need for the rower to overcome their own mass and accelerate from a fixed point, before transferring the power through the body to the handle (Bernstein et al., 2002; Greene et al., 2013). The increased inertial loads on the lower limbs while rowing on a fixed-based ergometer may increase the risk for overuse injuries or fatigue.

Bernstein et al. (2002) not only found that work performed per stroke was significantly greater on the fixed-head Row Perfect versus the floating-head (slide) Row Perfect, but also reported an increase in stroke length while rowing with the fixed head. Although the authors did not directly measure lumbar flexion at the catch, it was observed that the handle went further beyond the footplate on the fixed head as the trial progressed. This increase in stroke length at

the catch may be due to an increased trunk angle, specifically at the lumbar spine (Bernstein et al., 2002).

When comparing EMG activity and stroke kinematics, a few authors have compared ergometer styles (Caldwell et al., 2003; Fleming et al., 2014). Fleming et al. (2014) compared the C2 and the RP3 versus on water sculling in 10 male collegiate rowers during six, three-minute rowing intervals at increasing intensities. Electromyography of the rectus femoris, vastus medialis, biceps femoris and erector spinae were taken at each trial. Stroke kinematic data were collected to define time point in reference to percentage of stroke, 10 -20% being the early drive phase and 40-60% early recovery phase. Overall muscle activity was not significantly different between conditions, however when broken into the 10% stroke intervals, the rectus femoris mean muscle activity was greater on-water than on dynamic and stationary ergometers, with no difference between stationary and dynamic. The rectus femoris had two peaks, one at the early drive phase, active as the knee extensor, and at the early recovery phase, active as a hip flexor. With increasing intensities, the rectus femoris EMG activity was significantly greater during early drive phase on water and on the stationary ergometer (C2) compared to the RP3. As previously reported, the increase in rectus femoris muscle activity may be due to the need for stability on-water and to overcome the greater inertial forces on the fixed ergometer (Calloud et al., 2006; Bernstein et al., 2002). Erector spinae muscle activation was not significantly different across conditions. They concluded that the stationary ergometer more accurately mimicked on-water rowing in regards to EMG activity and muscle synergies (Fleming et al., 2014).

Caldwell et al. (2003) investigated sixteen young adult school rowers during a 2000 meter rowing trial. Lumbar flexion, at L1 to S1, and muscle fatigue of the erector spinae, specifically the multifidus, iliocostalis lumborum, and longissimus thoracis, were measured.

Muscle fatigue was classified as the median frequency of the power spectrum of the EMG signal. Significant increases in lumbar flexion was observed at the catch as the rowing trial progressed. Lumbar flexion was reported as a percentage of total range of lumbar flexion. At the first time point in the trial (20%) average flexion at the catch was 80% and increased to 87% by the last time point in the trial (95%). Similarly, all three erector spinae muscles increased %MVC activity at the catch as the trial progressed and median frequency for the iliocostalis and longissimus was significantly decreased following the trial with Pre MVC means of 117 ± 20 and 139 ± 19 and Post MVC means of 103 ± 16 and 129 ± 20 , respectively (Caldwell et al., 2003). This study concluded that high levels of lumbar flexion occur during the catch/early drive phase of the rowing stroke and are increased during the progression of the trial. Indirect measurement of fatigue of the erector spinae was assumed to be responsible for the increased flexion angles (Caldwell et al., 2003).

IMU Measured Kinematics of the Spine

Inertial measurement units (IMUs) have been used in various studies observing whole body and spine kinematics (Li & Chow, 2014; Umer et al., 2017). IMUs consist of tri-axial accelerometers, gyroscopes, and magnetometers. When attached to two segments (i.e. shank and thigh) surrounding a joint (i.e. knee joint), anatomical angles and accelerations in three degrees are reported. Orientations of each IMU on each segment are also reported as course, pitch and roll (Noraxon USA Inc., 2017). A validation study by Balasubramanian & Abbas (2013) compared Noraxon specific IMUs against Vicon's camera based three-dimensional motion capture system. The error obtained by Noraxon IMUs was 0.2° for static trials and 0.5° for dynamic trials, with a correlation coefficient between Vicon and Noraxon IMUs of 0.99. These sensors have been previously used to measure lumbar kinematics. Li & Chow (2014) used IMUs

to measure spinal curvature changes in the cervical, thoracic, and lumbar regions with increasing backpack load. Another study, used IMUs to assess trunk kinematics, thoracic and lumbar, during three rebar tying postures: stopping, one-legged kneeling, and squatting (Umer et al., 2017).

Summary

As of yet, no study has compared the slide-based ergometer (RP3) to the fixed C2 and investigated specifically erector spinae muscle activity and lumbar flexion in the sagittal plane. The closest study has investigated lumbar flexion and erector spinae activity and fatigue on the C2 alone (Caldwell et al., 2003), while one other found that, as rowers fatigue on a fixed ergometer, there is an increase in lumbar flexion (Wilson et al., 2013). As discussed, direct and indirect measurements of lumbar flexion have been made at the catch and been associated with fatigue and distance or ergometer style. Slide-based rowing ergometers have been shown to simulate on-water rowing in regards to energy demands and physiology, and at times, have a greater cardiopulmonary demand (Benson et al., 2011; de Campos Mello et al., 2014; Holsgaard-Larsen and Jensen, 2010). However, one study found that the stationary ergometer had a greater energy demand, possibly due to the weight of the erg in comparison to that of the slide-based ergometer (Greene et al., 2013). Similarly, some studies found that more work was required per stroke on the fixed ergometer, and that there was a delay in force to the handle (Bernstein et al., 2002; Green et al., 2013). The increased work required and delay in force to the handle relates to the increased lumbar flexion/trunk flexion angles seen on the fixed-base ergometers (Wilson et al., 2013), as well as the increased stroke length observed at the catch on the fixed ergometer in comparison to the slide-based ergometer (Bernstein et al., 2002).

These studies did not specifically measure fatigue at a certain muscle group, except for the study by Caldwell et al. (2003). However, some showed a trend in the correlation of overall general fatigue and rowing duration to changes in rowing kinematics, specifically the trunk or handle displacement (Bernstein et al., 2002; Fleming et al., 2014; Greene et al., 2013; Wilson et al. 2013). Fleming et al. (2014) found no significant difference in erector spinae muscle EMG between a slide- and fixed-base ergometer, however the rectus femoris was greatly increased in on-water and fixed ergometer rowing trials at the catch, possibly due to a combination of the hip flexion at the catch and the preparation for the knee extension at the early drive. The purpose of this study was to determine if there was a significant effect of distance on lumbar flexion and erector spinae muscle EMG while rowing on a slide-based RP3 rowing ergometer versus a fixed-based Concept2 ergometer during a 1000 m time trial in competitive female rowers.

Chapter III

Methods and Procedures

Introduction

This study was designed to examine the effect of distance and rowing ergometer style on lumbar flexion and lumbar erector spinae electromyography in competitive female rowers. The purpose of this chapter is to describe the methods and procedures used to obtain data in this study. The sections include a description of the subject characteristics followed by the design, data collection procedures, instrumentation, measurement techniques and procedures, and data analysis.

Description of Study Sample

The study sample consisted of 10 competitive female rowers between the ages of 18-35 years old. All subjects in the study previously trained on both rowing ergometers utilized in this study. Subjects had to meet the following inclusion criteria: at least one year experience rowing (on water and ergometer), participated in at least one race on water or ergometer, no history of back surgery, and no current injuries to the spine. The university's Human Subjects Committee reviewed the study prior to any data collection and subjects gave their informed consent.

Design of the Study

This study utilized a multiple-participant, within-subjects, repeated measures design. Subjects performed a standing maximum flexion test in order to get a baseline measurement to determine the full range of motion of the spine. Subjects also performed a maximal voluntary contraction of the lumbar erector spinae muscles to normalize electromyography data. Each subject performed one 1000-m time trial on each rowing ergometer, separated by approximately 48 hours. During each time trial, lumbar flexion and EMG of the erector spinae were collected at four different time points. Time 1 (T1) was at the first 250-m mark, Time 2 (T2) at the 500-m

mark, Time 3 (T3) at the 750-m mark and Time 4 (T4) at the 950-m mark. Capture time for each distance was approximately 10 seconds, which was enough time to capture 3 full strokes.

Data Collection Procedures

Instrumentation. The 1000-m time trials were collected in the WWU Women's Crew Erg Room in the Ridge Commons Building at Western Washington University on a Concept2 (Concept2, Morrisville, VT) rowing ergometer and a Row Perfect 3 rowing ergometer (RP3 Rowing, Bellingham, WA). Lumbar flexion was measured using Noraxon MyoMotion IMU motion capture technology during each time trial. Additionally, surface electromyography (EMG) was used to measure muscle activation of the erector spinae muscles during both trials.

Surface electromyography. The Noraxon Mini direct transmission system (Noraxon, Scottsdale, AZ, USA) was used to collect activity of the lumbar erector spinae muscles. Prior to electrode placement, subjects ES muscles were shaved and cleaned with alcohol wipes. Disposable, Noraxon, self-adhesive Ag/AgCl snap electrodes were placed parallel to the muscle fibers on the lumbar erector spinae on the right and left side, at the level of the spinous process of L2, 4cm lateral from the midline. Electrode placement was determined based on the SENIAM guidelines and previous research (Descarreaux et al., 2010; Dolan and Adams, 1998; Fleming et al., 2014). Correct placement of the electrodes was confirmed via visual examination during muscle activation.

Three-dimensional motion analysis. Noraxon MyoMotion hardware and software (Noraxon USA Inc., Scottsdale, AZ) was used to capture the kinematic data of the right knee, pelvis, lumbar and thoracic spine. Five inertial measurement units (IMU) were placed on the body via straps and adhesive tape to ensure minimal movement. Knee flexion, to determine drive and recovery phases, was obtained by attaching 1 IMU to the front of the tibia, in the middle of

the shank, and 1 IMU to the lateral aspect of the thigh, half way between the greater trochanter and lateral epicondyle. Spine kinematics were captured using 3 IMU sensors. The pelvis sensor was placed on the sacrum with the top of the IMU aligned with S1. The lumbar sensor was placed at the level of L1, with the top of the sensor aligned with L1. The top of the thoracic sensor was aligned with T1. The subject then stood as still as possible in anatomical position with the hips in a neutral position and feet hip width apart for 12 seconds. This was done to establish the local coordinate system and provide a reference angle on which to base the collected kinematic data. Noraxon MR3 software was used to measure, calibrate, and analyze the data received from the IMU sensors. Calibration for each subject was done before testing on both days. IMU technology has been validated and used in previous research involving highly dynamic movements and to observe lumbar flexion angles (Li & Chow, 2016)

Measurement techniques and procedures. Upon subjects entering the Ridge Erg Room, an informed consent and explanation of experiment protocol was given. Subjects were randomly assigned to an ergometer for the first session by means of drawing a card out of a box with the ergometer name written on it. In the second session, subjects performed the time trial on whichever ergometer they did not previously test on. Height and weight were measured and recorded and subjects were questioned on inclusion criteria such as: rowing experience, port or starboard rowers, and if they had a previous injury in regards to the low back within the last 6 months. Subjects were then instructed to warm up on the ergometer for 5 minutes at ‘light pressure’ at no more than 24 strokes per minute (spm) and with the last 10 strokes at a 28 spm to find the rhythm for their time trial (Wilson et al., 2013).

Each subject was instrumented with EMG electrodes on the lumbar erector spinae muscles bilaterally at the level of L2. IMU sensors were then attached to the right shank, right thigh, pelvis, L1 and T1.



Figure 1. EMG electrode placement on the lumbar erector spinae at the level of L2, 4cm from midline.

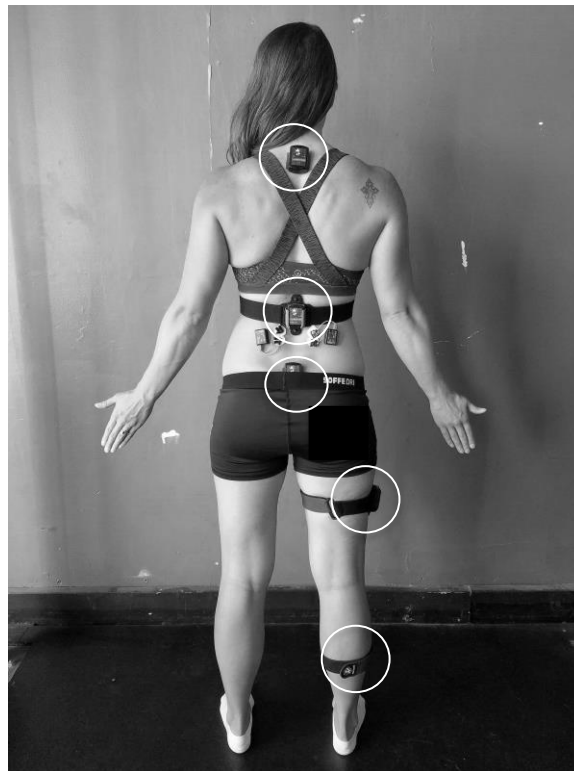


Figure 2. IMU sensor placement: right shank, right thigh, pelvis, L1 and T1.

Lumbar range of motion was obtained by taking a standing trial and a bent over full flexion trial using the Noraxon MyoMotion system. During the standing trial, the subjects simply stood in anatomical position and angle measurements were taken of the lumbar spine. During the full flexion trial, subjects were instructed to bend over at the waist as much as possible while standing with legs straight (Wilson et al., 2013). Lumbar flexion during the ergometer trials was expressed as a percentage of the subject's range of flexion based on a formula used by Caldwell et al. (2003). The equation included:

$$\% \text{ Flexion} = (\Theta_{\text{row}} - \Theta_{\text{standing}}) / (\Theta_{\text{full flexion}} - \Theta_{\text{standing}}) * 100$$

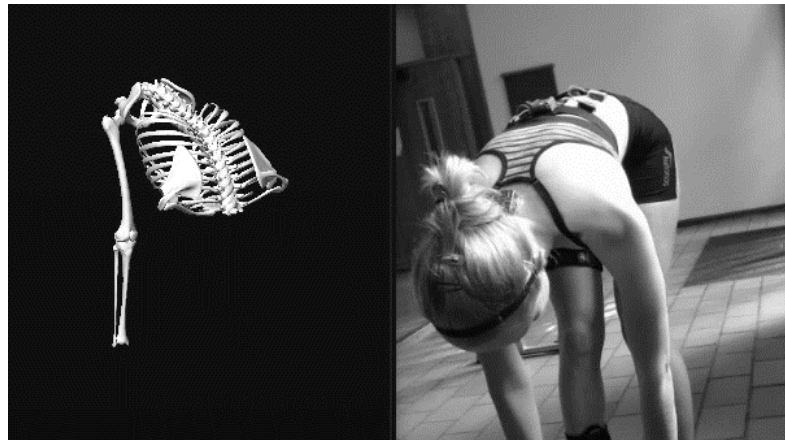


Figure 3. Lumbar range of motion; full flexion trial. Subject bent at waist with legs straight to try and reach maximum lumbar flexion.

Participants performed a single maximum voluntary contraction (MVC) for the lumbar erector spinae muscle group as a reference. MVC of the lumbar erector spinae was obtained by the subject laying prone, with the feet held down by the researcher and the subject then lifting their trunk off the ground with hands by the head. Maximal effort was encouraged for 5 seconds in order to capture a true MVC.

Upon completion of MVC, subjects were given a 2 minute rest before the start of the time trial. Subjects were instructed to row for 1000-m on the ergometer randomly assigned to their first collection day, at a maximal effort while maintaining a cadence of 28 spm.

During the 1000-m time trial, EMG and kinematic data were collected at four different distances; the 250-m, 500-m, 750-m and 950-m marks. Each capture duration lasted approximately 10 seconds to obtain data on at least 3 strokes, which were later averaged. Lumbar flexion and EMG were measured at three points of interest within the stroke, 10%, 20% and 60% of the drive phase, as described by Caldwell et al. (2003) and Hosea et al. (1989). The 10%, 20% and 60% of the drive phase was calculated by observing knee kinematics and dividing the time of the drive phase into 10% increments. Upon completion of the 1000-m time trial, the rower was allowed to recover before removing the EMG electrodes and IMU sensors.



Figure 4. Subject at 0% drive phase or catch on a Concept 2 ergometer



Figure 5: Subject at 0% drive phase or catch on a RP3 ergometer

Data Processing

The drive phase for each rowing stroke at each distance was analyzed by finding the maximum and minimum knee flexion angle in MR3.10. Maximum knee flexion indicated the beginning of the drive phase (0% drive phase) or the “catch.” Minimum knee flexion indicated the end of the drive phase (99% drive phase) or the “finish.” For the purpose of this study, EMG and kinematic data was only analyzed during this phase. Three drive phases in the middle of the 10 second collection at each distance were averaged.

EMG data were first rectified by taking the absolute value of the raw EMG signal, then smoothed using root mean square with a 50 ms window, and normalized to each subject’s maximum voluntary contraction (MVC) (Caldwell et al., 2003). Average EMG at 10%, 20% and 60% of the drive phase was calculated for each distance (250-m, 500-m, 750-m, and 950-m).

Percent lumbar flexion was determined by applying the raw joint angle data to the equation listed above and used by Caldwell et al. (2003). This allowed for a comparative analysis

between subjects since each subject had different baseline lumbar flexion angles. Average percent lumbar flexion was analyzed at 10%, 20% and 60% of the drive phase for each distance. Peak percent lumbar flexion was also calculated for the entire drive phase and subsequent percent of drive phase was recorded and averaged for all subjects at each distance, for both ergometers.

Data Analysis

Statistical analysis was performed using two, 3-way repeated measures analyses of variance (ANOVAs) to determine the effects of distance (250-m, 500-m, 750-m, and 950-m) and ergometer style (slide-based and fixed-based) on lumbar spine flexion and erector spinae muscle activity at three points during the drive phase (10%, 20%, and 60%). A 2-way repeated measures ANOVA was used to determine the effects of distance and ergometer style on peak lumbar flexion and timing of peak (relative to percent drive phase). Correlational analysis was also done to determine the relationship between mean lumbar flexion and mean erector spinae muscle activity while rowing on a Concept 2 versus RP3 over the 1000-m time trial. The alpha level was set at $p < .05$.

Chapter IV

Results and Discussion

Introduction

This study tested the difference between a fixed- versus slide-based rowing ergometer and the effect of distance across a 1000-meter time trial on lumbar flexion and lumbar erector spinae muscle activity during the drive phase. The hypothesis for this study was a null hypothesis that there would be no difference in lumbar flexion or erector spinae muscle activity between rowing ergometer styles and over each distance during the 1000 m. Percent lumbar flexion and EMG activity of the left and right lumbar erector spinae were measured and calculated during four distances (250 m, 500 m, 750 m, and 950 m) for both rowing ergometers (fixed and slide). These measures were further categorized to compare changes during 10%, 20% and 60% of the drive phase at each distance

Results

Demographics

Ten competitive female rowers, between the ages of 18- 35 years, who competed in a race either on an ergometer or on the water, have at least one year rowing experience, and had no current or previous low back pain in the last 6 months, were recruited for this study. The mean age was 26.00 ± 5.80 years, mean body mass of 68.31 ± 7.35 kilograms, and mean height of 1.71 ± 0.07 meters.

Time Trial

Time trial results for the 1000-m trial for both the fixed-base (C2) and slide -based (RP3) ergometers ranged from 220.3 seconds to 261.0 seconds (236.94 ± 12.45) and 210.6 seconds to 246.0 seconds (229.03 ± 10.69), respectively. A paired T-test was performed to analyze

significant differences between C2 and RP3 1000-m time and average 250-m split time. Average 1000-m time was significantly higher for the C2 versus the RP3 ($p = 0.01$, $d = 0.68$). Average 250-m split time was also significantly higher on the C2 versus the RP3 (118.69 ± 6.22 seconds and 114.54 ± 5.42 seconds, respectively ($p = 0.01$, $d = 0.71$) (Figure 6).

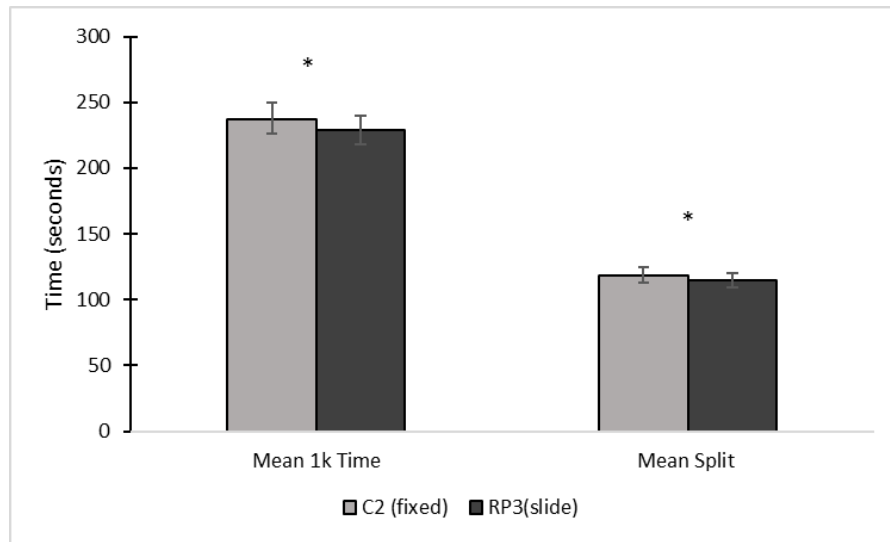


Figure 6. A graphical representation of mean 1000-m time trial times and mean (250 m) split times on a Concept 2(C2) versus the Row Perfect 3 (RP3). Error bars represent mean standard deviation of the means.

* denotes significance, $p < 0.05$

Lumbar Flexion

Mauchly's test of sphericity was significant. Therefore, the Greenhouse Geisser correction was used for this analysis. The three-way repeated measures ANOVA revealed a non-significant 3-way interaction of ergometer style, distance, and percent drive phase on lumbar flexion angle ($F [2.68, 24.15] = 0.75$, $p = 0.52$, $\eta_p^2 = 0.08$). The two-way repeated measures ANOVA revealed a non-significant interaction of ergometer style and distance ($F [2.19, 19.69] = 0.26$, $p = 0.79$, $\eta_p^2 = 0.03$), ergometer style and percent drive phase ($F [1.61, 10.45] = 0.53$, $p = 0.51$, $\eta_p^2 = 0.06$), and distance and percent drive phase ($F [2.68, 24.15] = 0.75$, $p = 0.52$, $\eta_p^2 = 0.08$) on mean percent lumbar flexion. The one-way repeated measures ANOVA showed there

was a non-significant effect of ergometer style on percent lumbar flexion ($F [1, 9] = 0.14, p = 0.72, \eta_p^2 = 0.02$) and a non-significant effect of distance on lumbar flexion ($F [1.2, 10.81] = 2.32, p = 0.16, \eta_p^2 = 0.21$). There was however, a significant effect of percent drive phase on lumbar flexion ($F [1.06, 9.51] = 14.74, p = 0.003, \eta_p^2 = 0.621$) with 60% of the drive phase having significantly less lumbar flexion than 10% ($p = 0.01$) and 20% ($p = 0.012$). There was no significant difference between 10% and 20% of the drive phase ($p = 1.0$) (Figure 7 and Figure 8).

There was no significant effect of ergometer style ($F [1,9] = 0.594, p = 0.461, \eta_p^2 = 0.062$) or distance on peak lumbar flexion during the drive phase ($F [1.12, 10.12] = 2.98, p = 0.112, \eta_p^2 = 0.249$). There was also no significant effect of ergometer style ($F [1, 9] = 1.695, p = 0.25, \eta_p^2 = 0.158$) or distance on percent of drive phase that peak lumbar flexion occurred ($F [3, 27] = 1.082, p = 0.373, \eta_p^2 = 0.107$). (Figure 9 and Figure 10).

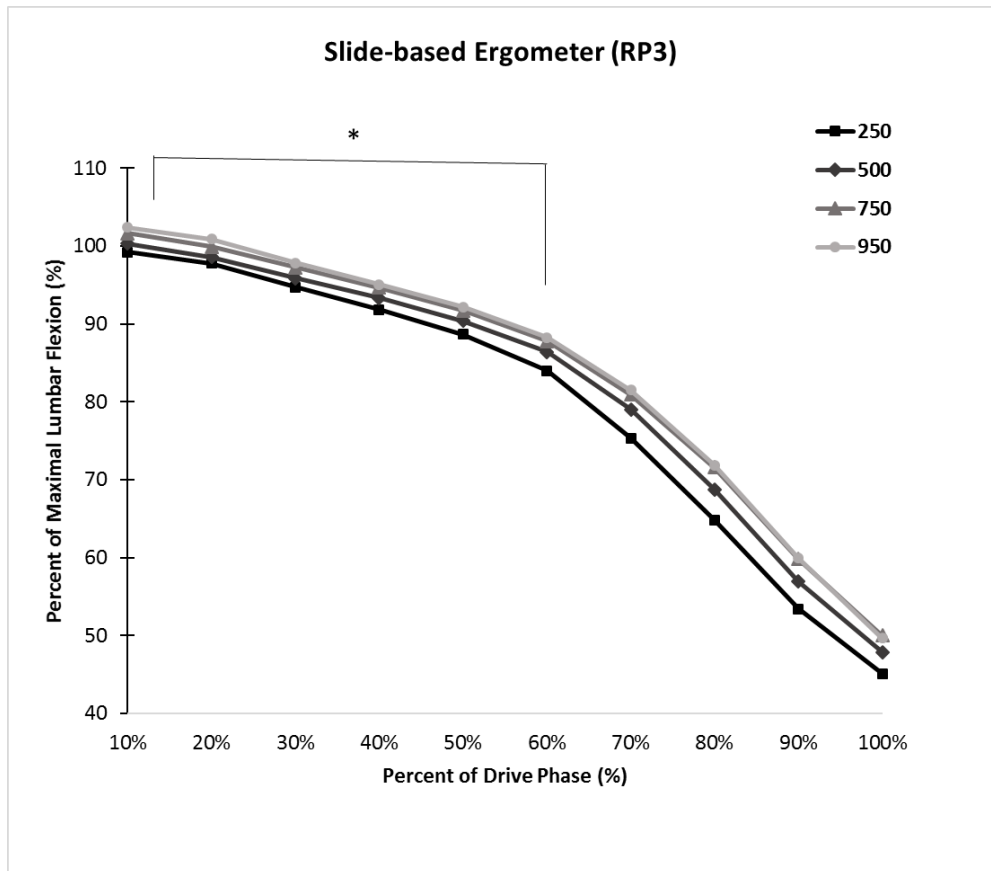


Figure 7. A graphical comparison of percent of maximal lumbar flexion over percent of the drive phase for each distance during the 1000-m time trial on the slide based ergometer (RP3). Statistical analysis was only done for 10%, 20% and 60% of the drive phase.

* denotes significance, $p < 0.05$

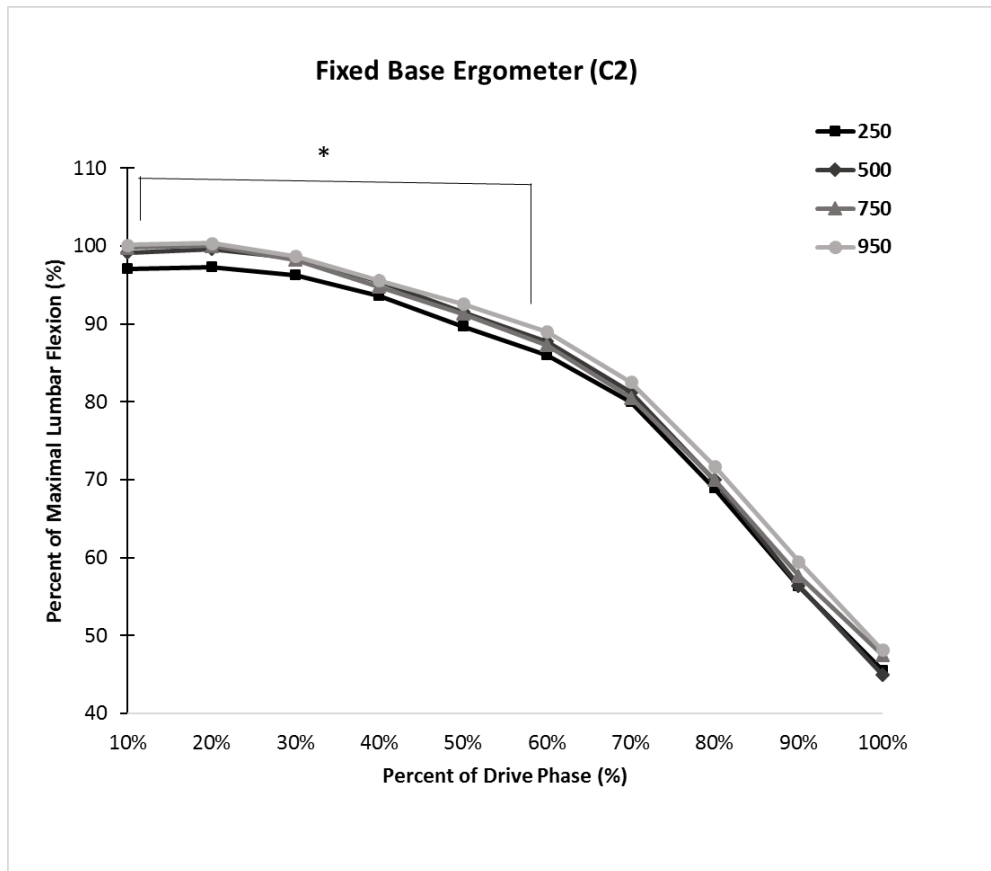


Figure 8. A graphical comparison of percent of maximal lumbar flexion over percent of the drive phase for each distance during the 1000-meter time trial on the slide based ergometer (RP3). Statistical analysis was only done for 10%, 20% and 60% of the drive phase.

* denotes significance, $p < 0.05$

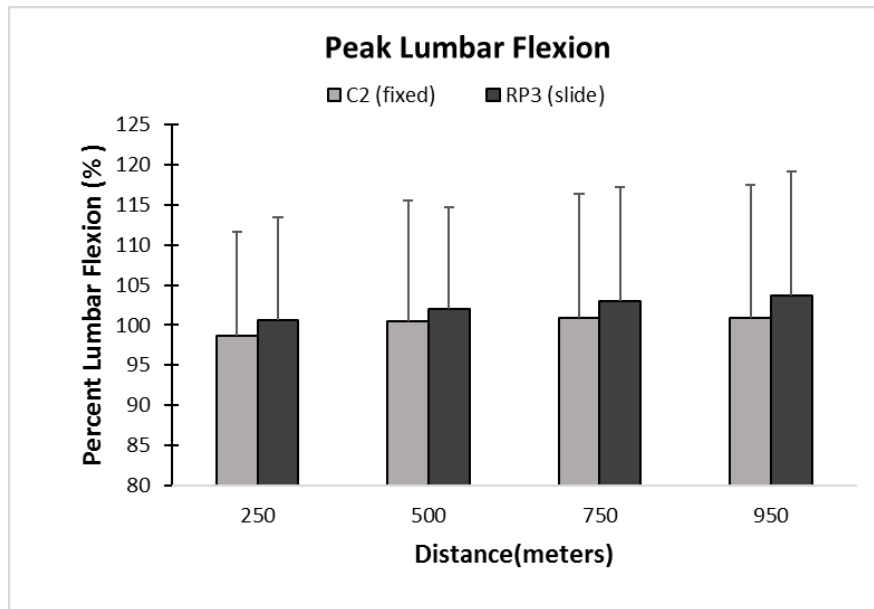


Figure 9. A graphical comparison of peak percent lumbar flexion for the C2 and RP3 at each distance during the 1000-meter time trial. Error bars represent standard deviation.

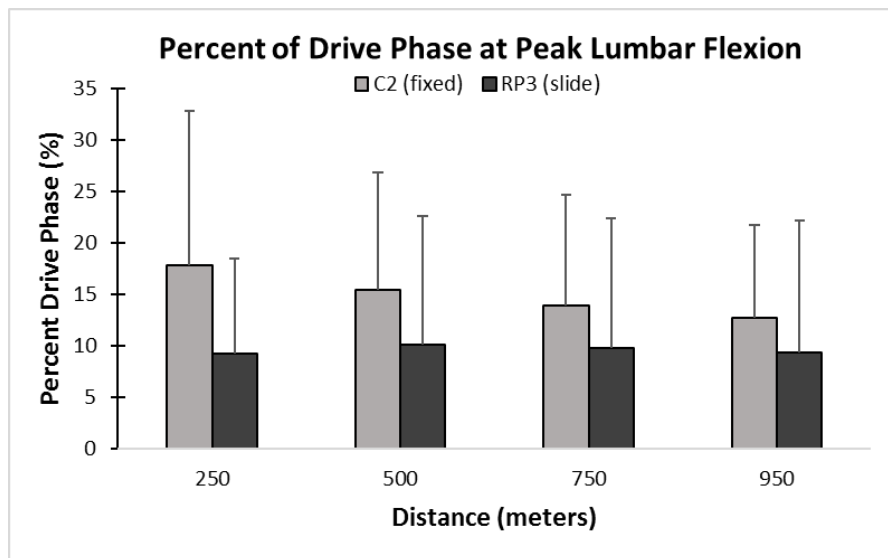


Figure 10. A graphical comparison of percent drive phase at peak percent lumbar flexion for the C2 and RP3 at each distance during the 1000-m time trial. Error bars represent standard deviation.

Lumbar Erector Spinae Muscle Activation

Mauchly's test of sphericity was significant; therefore, Greenhouse Geisser corrections were used again. For right lumbar erector spinae activity, the two-way repeated measures ANOVA revealed a non-significant interaction of ergometer style and distance ($F [1.44, 11.55] = 0.188, p = 0.761, \eta_p^2 = 0.023$) ergometer style and percent drive phase ($F [1.18, 9.42] = 2.713, p = 0.13, \eta_p^2 = 0.253$), or distance and percent drive phase ($F [1.72, 13.78] = 1.066, p = 0.361, \eta_p^2 = 0.118$). The three-way repeated measures ANOVA revealed a non-significant interaction of ergometer style, distance, and percent drive phase on right lumbar ES activity ($F [1.77, 14.13] = 0.30, p = 0.72, \eta_p^2 = 0.04$). For left lumbar erector spinae activity, there was also non-significant interactions of ergometer style and distance ($F [1.88, 15.06] = 0.94, p = 0.406, \eta_p^2 = 0.106$), ergometer style and percent drive phase ($F [1.03, 8.23] = 0.84, p = 0.388, \eta_p^2 = 0.095$), or distance and percent drive phase ($F [2.33, 18.638] = 0.86, p = 0.456, \eta_p^2 = 0.097$). The three-way repeated measures ANOVA revealed a non-significant 3-way interaction of ergometer style, distance, and percent drive phase on left lumbar ES activity ($F [1.84, 14.69] = 0.28, p = 0.74, \eta_p^2 = 0.03$). The one-way repeated measures ANOVA showed there to be a non-significant effect of ergometer style on right lumbar erector spinae ($F [1, 8] = 1.675, p = 0.232, \eta_p^2 = 0.173$), but a significant effect of ergometer style on left lumbar erector spinae ($F [1, 8] = 13.85, p = 0.006, \eta_p^2 = 0.634$). RP3 (slide) had significantly more left ES muscle activity than C2 (fixed) ($p = 0.006$). There was a non-significant effect of distance on both right ($F [2.59, 20.78] = 2.69, p = 0.08, \eta_p^2 = 0.251$) and left ($F [1.21, 9.65] = 0.15, p = 0.93, \eta_p^2 = 0.018$) lumbar erector spinae activity. There was however, a significant effect of percent drive phase for both right ($F [1.14, 9.12] = 21.55, p = 0.001, \eta_p^2 = 0.729$) and left lumbar erector spinae ($F [1.73, 13.86] = 23.26, p < 0.001, \eta_p^2 = 0.744$). Right lumbar erector spinae EMG was significantly higher at 60% of the

drive phase than 10% ($p = 0.002$) and 20% ($p = 0.008$). Right lumbar ES was higher at 20% than at 10% of the drive phase, however not significantly ($p = 0.29$). Left lumbar ES EMG was also significantly higher at 60% of the drive phase compared to 10% ($p = 0.001$) and 20% ($p = 0.004$). Muscle activity was not significantly different between 10% and 20% of the drive phase ($p = 0.691$). (See Figures 11 -14)

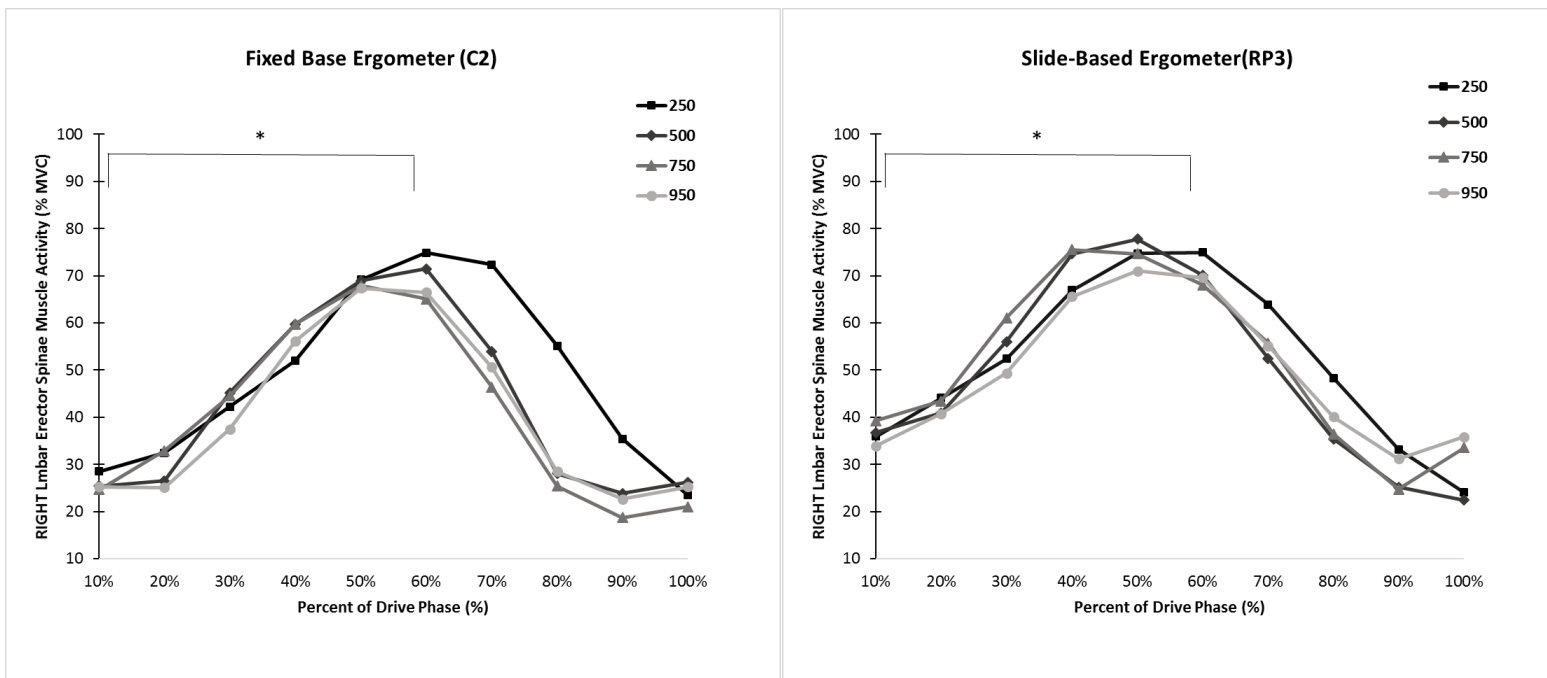


Figure 11 (left) and Figure 12 (right). A graphical comparison of normalized right lumbar erector spinae muscle activity over percent of the drive phase for each distance during the 1000-meter time trial on the fixed (C2) and slide based ergometer (RP3). Statistical analysis was only done for 10%, 20% and 60% of the drive phase.

* denotes significance, $p < 0.05$

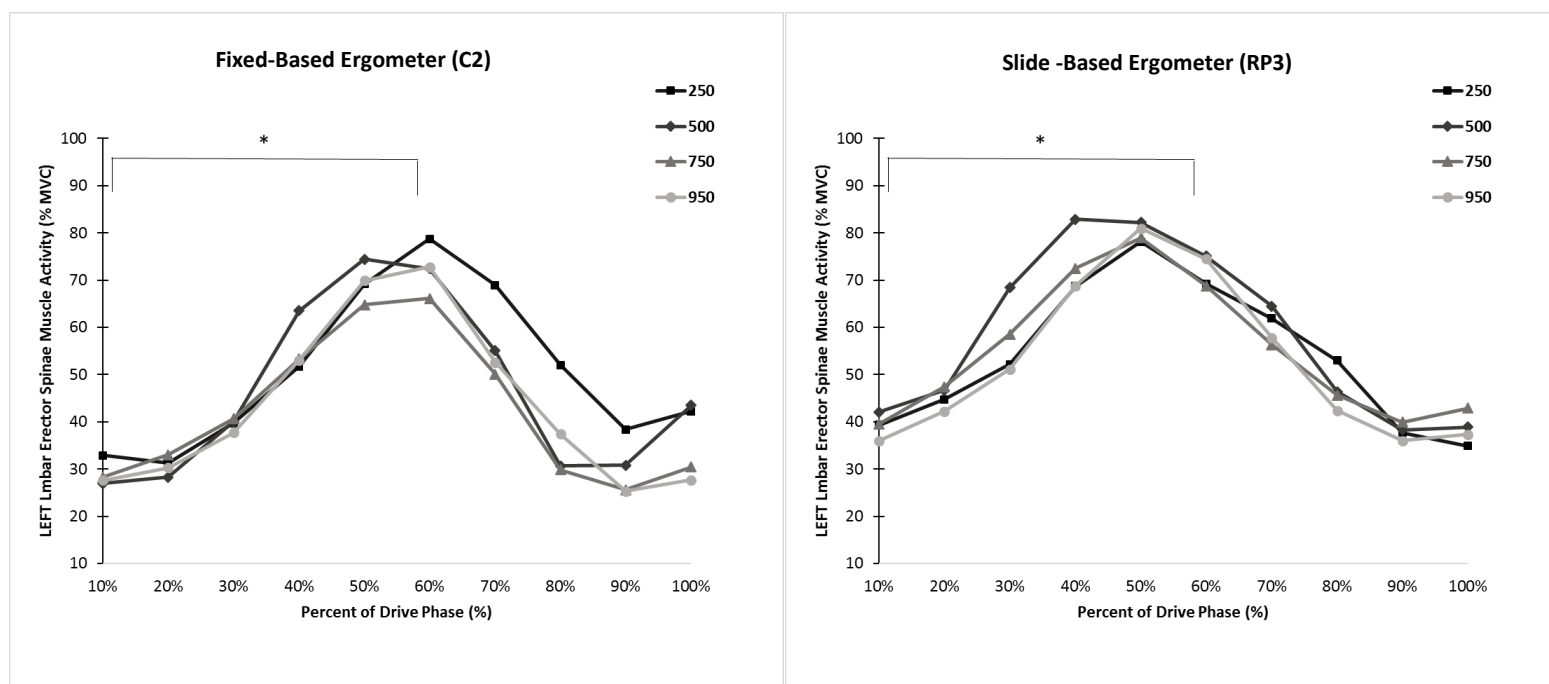


Figure 13 (left) and Figure 14 (right). A graphical comparison of normalized left lumbar erector spinae muscle activity over percent of the drive phase for each distance during the 1000-meter time trial on the fixed (C2) and slide based ergometer (RP3). Statistical analysis was only done for 10%, 20% and 60% of the drive phase.

* denotes significance, $p < 0.05$

Discussion

The purpose of this study was to determine the effects of distance (250 m, 500 m, 750 m, and 950 m) and percent drive phase on lumbar flexion and lumbar erector spinae muscle activity between a fixed-based and a slide-bases ergometer. The results support the null hypothesis that there would be no difference in peak or mean percent lumbar flexion and lumbar erector spine muscle activity over increasing distance. The results also supported the null hypothesis that there would be no difference in peak or mean percent lumbar flexion and right erector spinae EMG between rowing ergometer styles. Left lumbar erector spinae muscle activity, however, was significantly higher for the RP3 versus the Concept 2, rejecting the null hypothesis. Further analysis was done to determine at what point during the drive phase lumbar flexion and lumbar

erector spinae muscle activity was different. Results showed that at 60% of the drive phase, lumbar erector spinae muscle activity for both the right and left was significantly higher than at 10% and 20%. Results also showed that mean and peak percent lumbar flexion was significantly greater at the 10% and 20% of the drive phase versus 60% of the drive phase.

Each subject performed two 1000-m time trials on separate days. One on the RP3(sliding) and one on the C2 (fixed). Time trial times were significantly higher for the C2 versus the RP3. Mean 1000-m time and 250-meter split time for the C2 were, 236.94 ± 12.45 seconds and 118.69 ± 6.22 seconds, respectively. For the RP3, mean 1000-m time and 250-meter split time were 229.03 ± 10.69 seconds and 114.54 ± 5.42 seconds, respectively. Although no research has specifically compared the RP3 to the C2, the time trial times are consistent with other literature (de Campos Mello et al., 2014; USRowing, 2016; Smith and Hopkins, 2012), although most studies observed 2000-m time trials.

Results showed non-significant changes in mean percent lumbar flexion between rowing ergometer styles. This supports the null hypothesis. Across all distances, mean percent lumbar flexion was $95.22 \pm 5.12\%$ for the C2 and $95.91 \pm 4.45\%$ for the RP3. In this study, lumbar flexion was expressed as a percentage of the subject's maximal flexion angle. This allowed the comparison between subjects as each individual had varying degrees of standing lumbar angle. Caldwell et al. (2011) reported significantly increased percent lumbar flexion over time during a 2000-m time trial on a Concept 2. Mean percent lumbar flexion increased from approximately 74-89% between 20% and 95% of the 2000-m trial time. In the current study, percent lumbar flexion increased over distance for both ergometer styles, however not significant, there was a large effect size ($p = 0.16$, $\eta_p^2 = 0.21$). Wilson et al. (2013) also saw increased lumbar flexion angle at the last stages of a step test. Subjects of that study were instructed to maintain a certain

wattage and stroke rate during a step test designed to fully fatigue the subject. Comparing the fixed-base erg (C2) to on- water rowing, lumbar flexion from the first to last stage, increased by a mean of $4.4 \pm 3.7^\circ$ and $1.3 \pm 4.5^\circ$, respectively.

The observed differences between the reported literature above and the current study may be due to differences in the overall time trial distance. This study collected data on three strokes at 250-m, 500-m, 750-m and 950-m. Total time trial distance was only 1000-m, compared to the study by Caldwell et al. (2003), who tested the rowers on a 2000-m trial. The 1000-m time trial may not have been enough to fully fatigue the rowers and elicit changes, as it is also half of normal racing distance (USRowing, 2016). Bernstein et al. (2002) had each subject perform 20-minute ergometer trials and fatigue was not observed until 8 to 10 minutes in, whereas the subjects in this study were approximately working for only 4 minutes. As the current data suggested increases in lumbar flexion over increasing distance, it could be assumed that with an extended time trial the results may experience greater change.

The C2 and RP3 resulted in similar non-significant increases in percent lumbar flexion over increasing distance. Although no study, until now, has directly compared lumbar kinematics between an RP3 and C2, Wilson et al. (2013) did observe significant differences between a C2 and on-water rowing with the C2 increasing in lumbar flexion over time more than on-water rowing.

Lumbar flexion was further analyzed at three different points within the drive phase, (10%, 20% and 60%) at each distance. These time points were based on the findings of Caldwell et al. (2003), who compared the 10% and 60% drive phase. The 20% point was added to help determine if peak lumbar flexion was really occurring within the first 10% or if different ergometer styles would cause the peak to occur slightly later in the stroke. The results of this

study, similar to that of Caldwell et al. (2003), found that percent lumbar flexion was not significantly different at the 10% and 20% drive phase for either of the ergometer styles, however it was significantly lower at 60% of the drive phase. This difference in lumbar flexion angle between the beginning and middle of the drive is expected as the rower at that stage is starting to extend at the hips as the knees extend (USRowing, 2016).

To further understand differences in lumbar flexion, further analysis was done to determine peak percent lumbar flexion and at what percent of the drive phase that peak was occurring. As represented in Figure 9, peak lumbar flexion on the RP3 was non-significantly greater, with a medium effect size, at each distance interval versus the C2, ranging from $100.61 \pm 12.81\%$ to $103.66 \pm 15.49\%$ compared to $98.61 \pm 13.09\%$ to $100.96 \pm 16.53\%$, respectively ($p = 0.461$ $\eta_p^2 = 0.062$). However, what is interesting to note is that the RP3, in general, was reaching that peak just under the 10% of the drive phase, while the C2 was within the 10% to 20% of the drive. The differences observed in Figure 10 were not, however, statistically significant but did have large effect size ($p = 0.25$, $\eta_p^2 = 0.158$). This is most likely due to the large variance between subjects (note standard deviations) and small study population. Pollock et al. (2012) found significant delays in the timing of the trunk and arm kinematics over the course of a 2000-m time trial. Peak lumbar extension velocity was delayed during the mid-drive of the 1500-m mark versus the 250-m mark. In order to maintain mechanical efficiency, the trunk must maintain rigidity at the beginning of the drive to transfer the force from the legs, into the hips, trunk and arms (Hofmijster et al., 2008). These findings are consistent with a study by Green et al. (2013) who compared a RP3, C2s and C2d. Those authors found a delay in the delivery of power to the handle on the stationary C2, as did Bernstein et al. (2002). When observing a rower with delayed peak lumbar flexion, the knees start to extend, pushing the hips back and causing

the trunk to fall forward before correcting and increasing lumbar extension angular velocity (Pollock et al. (2012). One idea for a delayed peak lumbar flexion and delivery of power to handle, is that there is no momentum coming from the flywheel to the rower on a fixed-base. The rower must accelerate their full mass off of a fixed point, whereas on the RP3, the flywheel meets the rower and allows the use of a stretch shortening before pressing the flywheel in the opposite direction, much like plyometric squats (Green et al., 2013; Bernstein et al., 2002; Pollock et al., 2012). Ultimately, experiencing peak lumbar flexion later in the drive versus at the catch, or first 10% of the drive, may increase the risk of injury due to the greater angular velocities experienced at the joint and increased shear forces (Pollock et al., 2012; Morris et al., 2000).

Erector spinae muscle activity results for this study are slightly inconclusive, as left lumbar ES was significantly different on the RP3 versus the C2, however no significance was demonstrated for the right lumbar ES, there was a large effect size ($p = 0.232$, $\eta_p^2 = 0.173$). A study by Fleming et al. (2014) reported there were no significant differences in erector spinae muscle activity between a C2, RP3, and sculling in 10, male collegiate rowers. Further research needs to be done to better analyze ES muscle activity on a slide- versus fixed-based rowing ergometer.

When comparing left and right ES EMG activity across increasing distance, no significant difference was observed, however there was a large effect size on the right ES ($p = 0.08$, $\eta_p^2 = 0.251$). Previous research has found that over increased time or distance on rowing ergometers, EMG amplitude (%MVC) increased (Caldwell et al., 2003). Although the data reported in this study was not statistically significant, EMG amplitude (%MVC) of the lumbar ES appeared to decrease over time. It can be assumed that with increasing distance rowing, the

more fatigued an individual becomes. There is contradictory data on how the amplitude of an EMG signal is affected when a muscle is fatigued. Some studies reporting increases, such as Caldwell et al. (2003) and some reporting decreases (Dimitrova & Dimitrov, 2003). Ultimately, further analysis of the EMG signal must be done to determine fatigue in a dynamic setting.

Alternately, lumbar ES muscle activity (right and left) was significantly different across percent drive phase. At 60% drive phase left and right ES EMG was $58.59 \pm 10.01\%$ and 70 ± 5.68 versus the 10% and 20% drive phase ranging around 31% to 38%. This timing was in agreement with the findings from Caldwell et al. (2003) as the 60% drive phase is approximately the point at which the trunk starts to extend, causing the increased muscle activation. Further breakdown of the 10% drive phase increments would have been helpful for a more complete analysis of muscle activity and how ergometer styles may have played a role in the timing.

When observing Figures 11 through 14, notice that on the slide-based ergometer (RP3), the lumbar ES muscle activity is non-significantly greater at the 0% drive phase or “catch”, than the fixed-based erg (C2). A slight shift of the EMG curve towards the beginning part of the drive phase can also be observed with the RP3, whereas the C2 curve is more in the mid-drive. It is important to note that none of these differences are significant, possibly due to not having long enough time trials in order to properly induce a fatigue response.

There are a number of limitations to this study that could have affected the results reported. For example, the length of the time trial may not have been long enough to elicit the type of fatigue to which competitive female rowers are accustomed. A typical rowing race is 2000 m and training is often times much longer. Most of the ergometer studies listed above tested 2000 m. Therefore, change inducing fatigue may not have been properly reached. To continue with attempting to fatigue the athletes, the 1000-m trial was an all- out effort to the best

of their ability. This makes it difficult to control for self- motivation, although encouragement was given to each subject.

Additionally, half of the subjects were at the peak of their season, just a few weeks back from championships, while the other half were consistently competing but were a more recreational group. This, and the large range of ages causes some variance between the subjects and may account for the large standard deviations observed. Although this large variance in age and competitive level may allow for a better understanding of the population, more subjects may be necessary.

Lumbar flexion was measured using IMU sensors attached to the skin and may not fully reflect the movement of the bone. Similarly, lumbar flexion was calculated based on the orientation of a pelvis sensor relative to L1 sensor. The angle provided does not fully take into account each individual change between L5 thru L1, nor was it reported what caused the lumbar flexion. Pelvis orientation data would need to be further analyzed to understand if the lumbar flexion angle is increased due to posterior pelvic tilt, or due to increased flexion at the L1 and thoracic spine.

When using EMG, application and processing techniques play a large role in accuracy. Crosstalk, movement artifact, sweat, and electrode placement are just some of the many variable to think about when analyzing EMG data. There are also many ways to process an EMG signal and can often be difficult to find the proper equation for a specific exercise or movement.

Chapter V

Summary, Conclusions and Recommendations

Summary

This study observed the effects of rowing distance on mean and peak lumbar flexion, as well as timing of peak during the drive phase on two different rowing ergometer styles. Electromyography of the left and right lumbar erector spinae was also analyzed at each of the four distances and at three different percentages of the drive phase. Subjects performed two 1000-m time trials, separated by at least 48 hours. Ergometer style, fixed (C2) and slide(RP3), was randomly assigned for the first collection. Subjects were encouraged to perform an all-out-effort for 1000-m at 28 spm while instrumented with IMU and EMG sensors. Data was collected for 10 s so that three full strokes could be captured at 250 m, 500 m, 750 m and 950 m. For this study, EMG and Kinematics were analyzed only during the drive phase, determined by maximum and minimum knee angle. The drive phase of the rowing stroke was further separated into three percentages, 10%, 20% and 60% of drive phase, to compare the RP3 and C2. Results showed non-significant increases in peak lumbar flexion with increasing distance for both ergometers. Between ergometer styles, there were no significant differences for peak and mean lumbar flexion. Time to peak was earlier in the drive phase on the RP3 than the C2 across all distances, however not significantly. Significantly greater lumbar ES activation was accompanied by significantly less mean lumbar flexion at 60% of the drive phase compared to 10 and 20%. This was found across all distances and both ergometers. There was no significant effect of distance on mean right and left lumbar ES activity. Although there was no significant effect of ergometer style on right lumbar ES, there was a significantly higher left ES activation on the RP3 versus the C2.

Conclusions

A 1000-m time trial is not enough distance to elicit changes in lumbar flexion or erector spinae muscle activity as the rower becomes fatigued. Differences in ergometer style during the 1000-m is inconclusive at this point as the left ES EMG was greater on the RP3 than the C2, however not significantly different for the right ES. Future research is necessary to better understand the effects of a slide-based ergometer versus a fixed-based ergometer.

Recommendations

Future Research. Future research should include a greater time trial distance to properly induce fatigue while comparing ergometer styles. Additionally, further processing of the EMG signal of the erector spinae muscle should be done to better understand muscular fatigue and how it plays a role in spinal flexion characteristics. In regards to rowing kinematics and the effects on low back pain, further research should include full body motion capture coupled with forces from the foot stretchers to analyze the joint reaction forces occurring in the low back. A comparison of joint reaction forces of the spine between ergometers and on water could help in understanding a rower's risk. This study only analyzed competitive female rowers, further research should investigate the differences between men and women, young and older populations, and trained versus untrained. Learn to row clubs and Masters Clubs are growing as rowing becomes increasingly popular. More research should be done on how the off-season ergometer training may affect those populations. Future studies should examine the link and possible implications between low back pain and the timing of peak lumbar flexion in the drive phase.

Practical Applications. Results from this study suggest that a 1000-meter time may not be enough to produce changes in lumbar flexion or erector spine muscle activity due to fatigued

conditions. The percent of max lumbar flexion achieved was greater than 90 or 100% at times, possibly placing the rower at risk of low back injury or pain. This study also suggests that a rower will experience similar lumbar flexion and ES activity on a C2 and RP3, however if they want to have a better time trial performance, times on the RP3 were significantly faster.

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Appendix A
Informed Consent

Informed Consent

Project: Effect of Distance on Lumbar Flexion and Erector Spinae Electromyography on a Slide vs. Fixed-Based Rowing Ergometer

You are invited to participate in a research study investigating the effects of distance, gender and ergometer style on spinal flexion angle and muscle activity of the erector spinae muscles. To improve upon previous studies, this analysis aims to objectively provide a direct comparison of the slide based ergometer versus the fixed base ergometer. The results of this study will enhance our understanding of how athletes/ rowers are affected by fatigue and ergometer style and how factors that contribute to low back pain may be effected.

I UNDERSTAND THAT:

- 1) This experiment will involve the completion of a series of tasks that include a brief, low intensity warm-up on a rowing ergometer, maximum voluntary contraction of the erector spinae, a standing maximum spinal flexion trial, two 1000 meter time trials separated by at least 48 hours, and a brief low-intensity cool down. Additionally this experiment will require me to be instrumented with electrodes on my low back and an angle sensor attached to my low back and right leg. My participation will require approximately 60 minutes of my time for two sessions, for a total of two hours.
- 2) There may be risks during the rowing time trials, such as falling off of the ergometer, however rare and will be minimized by a spotter. I understand that exercise can lead to muscular soreness, cramping, pain, and fatigue. During testing, there is a risk of experiencing muscle soreness that should disappear after a period of rest. I understand that if exercise testing is painful, I can stop at any time. In addition, I am aware that I could experience delayed onset muscle soreness (DOMS) after the session that could last for 24-72 hours. The safeguards that will be used minimize potential muscle soreness include a warm-up, acclimation, and cool down period. If I feel like I cannot or should not perform any of these tasks, I could opt out from the participation in this study.
- 3) My participation is voluntary. I am able to withdraw from the study at any point in time without penalty.
- 4) All information is confidential. My signed consent form will be kept in a locked cabinet separate from any information tying me to this study. Only the primary researcher will have access to any data gathered in this study. My name will not be associated with any performances or relevant data to the study.
- 5) My signature on this form does not waive my legal rights of protection.
- 6) This experiment is conducted by Nicole Yvette Kelp under the supervision of Dr. Dave Suprak. Any questions that you may have about the experiment or your participation may be directed to the investigators at (425)244-7668.

If you have any questions about your participation or your right as a research participant, you can contact the WWU Human Protections Administrator (HPA), (360)650-3220. If during or after participation in this study you suffer from any adverse effect as a results of participation, please notify the researcher directing the study or the WWU Human Protections Administrator.

I have read the above description and agree to participation in this study.

Participant's Signature

Date

Participant's PRINTED NAME

Note: Please sign both copies of the form and retain the copy marked "Participant"

Appendix B
Protocol Checklist

Subject ID:		Date: / /	
Informed Consent Signed		YES / NO	
Informed Consent Understood/Questions Answered		YES / NO	
Age:	Weight:	Height:	
Gender: M / F		PORT / STARBOARD / BOTH	
1000m Time:	Average Watts:	Avg Split:	
At least 6 months Experience on Rowing Ergometer?		YES / NO	
Current low back pain or injury?		YES / NO*	
<i>*if yes subjects must be excluded from study</i>			
5 minute warm up on rowing ergometer completed?		YES / NO	
Discuss Protocol: 1) We will fully instrument you with EMG and goniometer 2) Once instrumented, you will perform the End Range of Flexion Test 3) You will then be instructed on the 1000 meter time trial protocol (max effort at 28 spm) 4) After the time trial you we will be given time to rest then de-instrumented			
Instrumentation Completed? EMG sensors <input type="checkbox"/> Left Erector Spinae <input type="checkbox"/> Right Erector Spinae IMU Sensors <input type="checkbox"/> Shank <input type="checkbox"/> Thigh <input type="checkbox"/> Pelvis <input type="checkbox"/> Lower Thoracic <input type="checkbox"/> Upper Thoracic			
MVCs Performed		YES / NO	
End Range of Flexion Test		YES / NO	
Standing:		Bent Over:	
Ergometer Randomization		YES / NO	
Explanation of 1000 meter Time Trial:		YES / NO	
"For this time trial you will be rowing for 1000 meters in an all-out effort. You re limited to 28 strokes per minute. We will collect data at the 250, 500, 750, and 950 meter marks. If at any time you cannot or don't want to continue, you may stop. Once you have finished the 1000 meter piece your time, average split and average wattage will be recorded. You will be de-instrumented and then give some time to cool down. DO YOU HAVE ANY QUESTIONS?"			

	250m	500m	750m	950m
Time				
Split Time				

Appendix C

Descriptive Statistics

Mean Erector Spinae Muscle Activity

Key: Erg Type:1=RP3; 2=C2

Distance: 1=250m; 2=500m, 3=750m, 4=950m

Percent Drive Phase: 1=10%; 2=20%, 3=60%

Measure: LEFT_ES_EMG

ERG_TYPE	DISTANCE	PERCENT_DRIVE_PHASE	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
1	1	1	39.338	10.053	16.155	62.520
		2	44.778	11.480	18.305	71.251
		3	69.212	9.037	48.373	90.052
	2	1	42.058	11.757	14.947	69.169
		2	46.666	13.476	15.590	77.743
		3	75.064	11.986	47.425	102.704
	3	1	39.567	11.493	13.065	66.069
		2	47.429	15.516	11.648	83.209
		3	68.826	10.394	44.857	92.794
	4	1	36.012	10.854	10.982	61.043
		2	42.232	12.788	12.743	71.721
		3	74.478	10.470	50.335	98.621
2	1	1	32.886	7.481	15.634	50.137
		2	31.258	7.684	13.538	48.977
		3	44.778	11.480	18.305	71.251
	2	1	26.970	7.354	10.011	43.929
		2	28.316	8.313	9.146	47.487
		3	46.666	13.476	15.590	77.743
	3	1	28.251	7.171	11.715	44.787
		2	33.001	7.917	14.743	51.258
		3	47.429	15.516	11.648	83.209
	4	1	27.637	7.773	9.712	45.562
		2	30.302	8.009	11.833	48.771
		3	42.232	12.788	12.743	71.721

Measure: RT_ES_EMG

ERG_TYPE	DISTANCE	PERCENT_DRIVE_PHASE	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
1	1	1	35.895	9.164	14.763	57.026
		2	44.074	11.194	18.259	69.888
		3	74.963	7.613	57.408	92.518
	2	1	36.715	11.208	10.870	62.560
		2	40.890	11.651	14.022	67.758
		3	70.111	8.396	50.749	89.473
	3	1	39.236	11.927	11.733	66.739
		2	43.397	12.953	13.527	73.267
		3	68.027	9.462	46.207	89.846
	4	1	33.929	9.522	11.971	55.888
		2	40.726	12.185	12.627	68.826
		3	69.580	7.899	51.364	87.796
2	1	1	28.507	6.377	13.800	43.213
		2	32.423	7.626	14.837	50.009
		3	74.874	8.228	55.901	93.848
	2	1	25.400	7.870	7.253	43.548
		2	26.506	8.202	7.591	45.420
		3	71.482	7.518	54.146	88.819
	3	1	24.628	6.787	8.976	40.279
		2	32.923	8.784	12.667	53.179
		3	65.120	5.236	53.046	77.194
	4	1	25.271	6.123	11.151	39.390
		2	25.079	6.011	11.218	38.941
		3	66.491	4.085	57.071	75.912

Mean Percent Lumbar Flexion

Key: Erg Type:1=RP3; 2=C2

Distance: 1=250m; 2=500m, 3=750m, 4=950m

Percent Drive Phase: 1=10%; 2=20%, 3=60%

Measure: LUMBAR_FLEXION_10_20_60

ERG_TYPE	DISTANCE	PERCENT_DRIVE_PHASE	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
1	1	1	99.230	3.814	90.602	107.859
		2	97.802	3.749	89.322	106.282
		3	86.035	5.295	74.056	98.014
	2	1	100.317	3.889	91.519	109.116
		2	98.575	3.909	89.732	107.418
		3	87.766	5.876	74.474	101.058
	3	1	101.675	4.358	91.817	111.532
		2	99.916	4.226	90.356	109.476
		3	87.276	6.754	71.998	102.554
	4	1	102.407	4.864	91.403	113.411
		2	100.894	4.594	90.501	111.287
		3	89.003	6.753	73.726	104.279
2	1	1	97.092	4.152	87.699	106.485
		2	97.330	4.100	88.056	106.604
		3	86.036	5.295	74.058	98.015
	2	1	98.196	4.855	87.214	109.178
		2	99.624	4.779	88.813	110.435
		3	87.767	5.876	74.475	101.060
	3	1	99.792	4.885	88.742	110.842
		2	100.038	5.017	88.688	111.388
		3	87.277	6.754	71.999	102.555
	4	1	100.143	5.226	88.321	111.964
		2	100.369	5.371	88.218	112.520
		3	89.003	6.753	73.726	104.279

Peak Lumbar Flexion

Key: Erg Type:1=RP3; 2=C2

Distance: 1=250m; 2=500m, 3=750m, 4=950m

Measure: PEAK_LUMBAR_FLEXION

ERG_TYPE	DISTANCE	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	100.616	4.051	91.453	109.779
	2	102.049	4.007	92.984	111.113
	3	103.009	4.491	92.851	113.167
	4	103.659	4.900	92.575	114.743
2	1	98.613	4.138	89.252	107.975
	2	100.451	4.761	89.681	111.221
	3	100.843	4.934	89.681	112.006
	4	100.957	5.228	89.131	112.783

Percent of Drive Phase at Peak Lumbar Flexion

Key: Erg Type:1=RP3; 2=C2

Distance: 1=250m; 2=500m, 3=750m, 4=950m

Measure: PEAK_LF_PERCENT_DRIVE_PHASE

ERG_TYPE	DISTANCE	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	9.200	2.920	2.594	15.806
	2	10.100	3.959	1.143	19.057
	3	9.800	3.988	.778	18.822
	4	9.300	4.047	.145	18.455
2	1	17.800	4.730	7.100	28.500
	2	15.400	3.615	7.221	23.579
	3	13.900	3.401	6.207	21.593
	4	12.700	2.856	6.239	19.161

Appendix D
Raw Subject Data

Subject demographics

Subject	Sex	Age	Weight (lbs)	Height (in)	Port/Starboard
1	F	35	135	66	S
2	F	26	165	71	S
3	F	21	150	70	P
4	F	22	135	69	P
5	F	21	150	67	S
6	F	21	155	70	P
7	F	27	135	64	Both
8	F	35	185	70	P
9	F	34	138	64	S
10	F	22	165	65	both

Subject time trial times for both ergometers and average split time

Subject	C2 1k Time (s)	C2 Avg. Split (s)	RP3 1k Time (s)	RP3 Avg. Split (s)
1	261.00	130.50	246.00	123.00
2	228.00	115.00	222.00	111.00
3	235.00	118.00	229.00	114.00
4	231.00	115.00	228.00	114.00
5	220.30	110.00	210.60	105.33
6	227.00	114.00	225.55	112.78
7	243.00	122.00	237.00	118.80
8	230.70	115.40	223.10	111.55
9	252.00	126.30	225.00	112.60
10	241.40	120.70	244.00	122.32

Subject lumbar flexion range of motion trial data

Subject	Standing Lumbar Angle (degrees)	Max Lumbar Flexion Angle (degrees)	Lumbar Flexion Range of Motion (degrees)
1	1.90	38.4	36.50
2	2.10	37.76	35.66
3	-2.60	56.50	59.10
4	1.20	53.50	52.30
5	-1.80	55.90	57.70
6	-15.40	38.40	53.80
7	-6.10	60.10	66.20
8	-13.20	50.10	63.30
9	-3.80	58.10	61.90
10	-0.70	62.80	63.50